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A Test of the International Convergence Hypothesis Using Panel Data

Norman V. Loayza

This model for estimating an economy's rate of convergence to its own steady state uses a neoclassical Solow model and accounts for the presence of country-specific effects. The estimated rate of convergence is 0.0494, implying a half-life of about 14 years.

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Summary findings

Loayza, using a neoclassical Solow model, estimates an economy's rate of convergence to its own steady state. Using panel data for a sample of 98 countries, he applies Chamberlain's (1984) estimation procedure to account for the presence of country-specific effects resulting from idiosyncratic unobservable factors. This procedure also prevents the estimation bias due to measurement error in GDP.

Controlling, additionally, for the country's level of education, he estimates the rate of convergence to be 0.0494, which implies a half-life of about 14 years.

This estimated rate of convergence is about two and a half times higher than those obtained by Barro and Sala-i-Martin (1992) and Makiw, Romer, and Weil (1992). Loayza claims that those estimates are biased toward zero because they fail to account for country-specific effects.

Finally, he estimates the capital share in production to be 0.347, which is very close to the accepted benchmark value.

This paper — a product of the Macroeconomics and Growth Division, Policy Research Department — is part of a larger effort in the department to understand the determinants of economic growth. Copies of the paper are available free from the World Bank, 1818 H Street NW, Washington, DC 20433. Please contact Rebecca Martin, room N11-043, extension 39026 (30 pages). August 1994.

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I. INTRODUCTION

G. Mankiw, D. Romer, and D. Weil in their paper "A Contribution to the Empirics of Economic Growth" (1992) argue that the Solow neoclassical growth model, when augmented to include human capital, provides a very satisfactory guide to understanding the process of economic growth among nations. In fact, they report that 80% of the international variation in income per capita can be explained by the augmented Solow model.

Mankiw, et. al., provide convincing arguments that the empirical evidence is consistent with the predictions of the model in terms of the effects of investment, both in physical and human capital, and population growth on the level of output. They also point out that, when properly specified, the model predicts "conditional" convergence. This phenomenon has received much attention and is well documented in papers such as Barro and Sala-i-Martin (1992), De Long (1988), Dowrick and Nguyen (1988), and Easterlin (1981). We wish to add to this literature; in fact, the main focus of this paper is the econometric study of the "conditional" convergence hypothesis.

From the perspective of economic methodology, there is still one more reason why the Solow model is appropriate for the international study of growth. The Solow model is a "positive" theory of growth in the sense that its explanation uses variables that we can observe and measure, although not without considerable difficulty, directly from the real world. The model takes as its primary variables the investment rate, the population growth rate, and the rate of technological change. In studies of the "conditional" convergence hypothesis, this "positive" feature of the Solow model is crucial because it informs us as to the variables that appropriately condition for the steady-state of each economy.

This paper uses the classical Solow model as a general guide. The Solow model considers an efficiency parameter in the aggregate production function. Most cross-sectional studies of growth and convergence (including Mankiw, et. al.) identify the efficiency parameter with the constant in their regression equations. In so doing, these studies assume that all countries have the same level of efficiency in using the factors of production. If we consider that the efficiency parameter depends on elements such as fiscal and taxation policies, openness to trade, public infrastructure, political stability, and level of education, we cannot but reject the assumption that all countries have a common efficiency parameter. In this paper, we deal explicitly with the issue of different efficiency parameters by identifying them with country-specific factors, which can be accounted for by using panel data. In principle, we would like to obtain information about all those variables that constitute the efficiency parameter. Unfortunately, adequate information is unavailable for most of those variables. Chamberlain (1984) shows a method to avoid the omitted-variable bias that occurs when all or some of the elements of such country-specific factors are unavailable. We will use Chamberlain's proposed methodology. In the estimation section of the paper, we consider first the case in which no information as to the country-specific factors is available, and second, the case in which we have information concerning one of its elements, namely, the country's level of education.

II. THE MODEL

We use a general version of the neoclassical growth model. There are different treatments of this class of models in the literature. Barro and Sala-i-Martin (1992) take a utility maximization approach; thus, the resulting levels and growth rates, both in the transition period and in the steady state, are functions of the underlying parameters of the representative consumer's utility function and technology. Mankiw, et.al, (1990) argue that the Solow (1956) model, in which the savings and population growth rates are taken as fixed and exogenous, is a good guide to the study of the differences in growth performance across countries. In this approach, the resulting levels and growth rates are functions of the country's technology and "observable" variables such as the investment ratios in physical and human capital and the population growth rate.

A common feature of all versions of the neoclassical growth model is that economies tend to converge towards their own long-run growth rates. As Rebelo (1991) points out, this is due to the assumption of decreasing returns in the set of reproducible factors in the production function. Furthermore, the above-cited versions of the neoclassical model predict "conditional convergence." In simple terms, conditional convergence means that if countries had the same preferences and technology, poor countries would grow faster than rich ones. The rapid recovery of most Western European countries after the destruction caused by World War II and their catch-up to the United States is a demonstration of what is meant by conditional convergence (Dowrick and Nguyen 1989).

To summarize, convergence means that the growth rate of an economy is positively related to the distance between its current level and its long-run goal. Mathematically, the concept of convergence can be expressed in the following equation:

$$\frac{d\log\hat{y}_t}{dt} = \beta(\log\hat{y}^* - \log\hat{y}_t) \tag{1}$$

where $\hat{y}_t$ and $\hat{y}^*$ are the current and steady-state levels of output per effective worker (which adjusts for the trend of exogenous population growth and technological progress), respectively; and β is the convergence rate, which is a function of the underlying parameters of preferences and technology. Clearly, convergence toward the steady state is achieved if $\beta>0$.

Equation (1) is the result of the linearization of the transition path of output per effective worker around its steady-state value. We are assuming that the population of workers grows exponentially at rate, say, n, and that the available technology also grows exponentially at rate, say, g. Both rates are exogenously determined. They will dictate the growth rates in the steady-state; thus, the level of output will grow in the long run at rate n+g, and the level of output per worker, at rate g. Clearly, the level of output per effective worker will be constant in the long run (this is why we need to formulate the equation of convergence in terms of quantities per effective worker).

Integrating equation (1) from (t-r) to t and expressing output in per-worker terms, we get

$$\log y_t = (1-e^{-r\beta})\log\hat{y}^* + e^{-r\beta}\log y_{t-r} + (1-e^{-r\beta})gt + e^{-r\beta}gr + (1-e^{-r\beta})\log A_0 \tag{2}$$

where y is output per worker and A_0 represents the shifting parameter in the neoclassical production function. We assume that, conditional on $\hat{y}^*$, ß is constant for all countries. Following Mankiw, Romer, and Weil (1992), we assume that the rate of technological progress, g, is the same for every country.

As Barro and Sala-i-Martin (1992) point out, in cross-country empirical studies of convergence, it is crucial to hold fixed the steady-state levels of output per effective worker, $\hat{y}^*$. How can we do this? As it was said above, if we follow the utility-maximization approach, the steady-state levels are functions of the underlying parameters of the representative consumer's utility function and technology. It is almost impossible to directly obtain estimates of those parameters for most countries around the world. However, we can be informed as to the values of those parameters across countries by observing the variables that are determined by such parameters. Some of those variables are the investment ratios, the population growth rates, and the relative shares of the factors of production.

The Solow model, using a Cobb-Douglas production function, gives a closed-form solution for $\hat{y}^*$:

$$\log\hat{y}^* = -\frac{\alpha}{1-\alpha}\log(n+g+\delta)+\frac{\alpha}{1-\alpha}\log s \tag{3}$$

where s is the investment rate of the economy, δ is the depreciation rate of the capital stock, and α is the capital share of output.

Substituting equation (3) into (2), we obtain an expression for the evolution of output per worker in the transition path in terms of observable variables. Normalizing r=1, we get

$$\log y_t = -(1-e^{-\beta})\left(\frac{\alpha}{1-\alpha}\right)\log(n+g+\delta) + (1-e^{-\beta})\left(\frac{\alpha}{1-\alpha}\right)\log s$$
$$+ e^{-\beta}\log y_{t-1} + (1-e^{-\beta})gt + e^{-\beta}g + (1-e^{-\beta})\log A_0 \quad (4)$$

In order to see more clearly the effect of each variable to the rate of growth in the transition to the steady state, we can rewrite equation (4) as follows:

$$\log y_t - \log y_{t-1} = -(1-e^{-\beta})\left(\frac{\alpha}{1-\alpha}\right)\log(n+g+\delta) + (1-e^{-\beta})\left(\frac{\alpha}{1-\alpha}\right)\log s$$
$$-(1-e^{-\beta})\log y_{t-1} + (1-e^{-\beta})gt + e^{-\beta}g + (1-e^{-\beta})\log A_0 \quad (5)$$

We will use this specification as a guideline but will not apply it literally. If the rate of convergence ß is positive, we can predict the signs of the coefficients of each term in equation (5). Let us examine each of those terms in turn. The first one indicates that, for given g and δ, the rate of growth of the working-age population, n, is negatively related to the growth of per capita output. The second term indicates that the more a country saves and invests, the more it grows. The third term tells us that countries grow faster if they are poor with respect to their potential. The fourth term suggests the presence of a time-specific effect in the growth equation. The fifth term tells us that increases in the rate of technological change bring about higher per capita growth rates. In the sixth term, the parameter A_0 represents all those elements that determine the efficiency of factors of production and available technology to create wealth; of course, the greater such efficiency, the greater the rate of growth of the economy. Some of the elements that compose the A_0 parameter are government policies, natural resources, openness to foreign trade, and quality of education of the population. This term suggests the presence of a country-specific effect, which may well be correlated to the investment and population growth rates, as well as to the initial level of output per worker in each particular economy.

The above interpretation of equation (5) suggests a natural regression to study the convergence hypothesis. Let us rewrite a more general form of equation (4) for a given country i:

$$\begin{gathered}\log y_{i,t} = \theta_n \log(n_{i,t}+g+\delta) + \theta_s \log s_{i,t} + (1+\gamma)\log y_{i,t-1} + \xi_t + \mu_i + \epsilon_{i,t} \\ E\left[\epsilon_{i,t} \,|\, (\log(n_{i,1}+g+\delta), \log s_{i,T}), \ldots, (\log(n_{i,T}+g+\delta), \log s_{i,T})\right] = 0 \\ for\ t=1,\ldots,T\end{gathered} \tag{6}$$

where ξ_t and μ_i represent the time-specific and the country-specific effects, respectively; and θ_n, θ_s, and γ are parameters to be estimated. The disturbance term $\epsilon_{i,t}$ is assumed to be uncorrelated with all leads and lags of the independent regressors $\log(n_{i,t}+g+\delta)$ and $\log(s_{i,t})$; in particular, this implies that such regressors are not affected by the evolution of output, just as the Solow model assumes. Note that the disturbance $\epsilon_{i,t}$ is not assumed to be i.i.d.. Thus, the model does not impose either conditional homoskedasticity or independence over time on the disturbances within each country. We want to allow for serial correlation in the error term because there may be some excluded variables that present short-run persistence; of course, the μ_i component accounts for long-run persistence of excluded variables that may be correlated with the independent regressors $\log(n_{i,t}+g+\delta)$ and $\log(s_{i,t})$.

Let us summarize what our working assumptions are. First, we assume that a log-linear specification for the regression equation is appropriate. This specification is quite popular in the growth literature both because it comes naturally from a Cobb-Douglas type production function and because it has proven to be relatively robust (Maddison, 1987). Second, we assume that conditional on the steady-state level of output per worker, $\hat{y}^*$, the rate of convergence, ß, is approximately equal across countries. Third, we assume that the working-age population growth rate and the ratio of investment in physical capital condition appropriately for $\hat{y}^*$. A related assumption says that g, α, and δ are approximately the same for all countries. Finally, we assume that the working-age population growth rate and the physical capital investment ratio are strictly exogenous.

The hypothesis of conditional convergence can be tested using regression equation (6). In fact, conditional convergence implies that the coefficient on $\log(y_{i,t-1})$, $(1+\gamma)$, is less than 1.

As it was said in the introduction, previous studies of convergence have used cross-sectional data. This forced the use of some rather restrictive assumptions in the econometric specification of the models. For instance, Mankiw, et.al, assume that $\log A_0$ is independent of the investment ratio, the working- age population growth rate, and the initial level of output per worker. This amounts to ignoring country-specific effects; for example, their assumption implies that government policies regarding taxation and international trade do not affect national investment, or that the endowment of natural resources does not influence fertility. As Mankiw, et. al. say, "If countries have permanent differences in their production functions -that is, different A_0's- then these A_0's would enter as part of the error term and would be positively correlated with initial income. Hence, variation in A_0 would bias the coefficient on initial income toward zero (and potentially would influence the other coefficients as well)" (p.424). Furthermore, since only one cross-section is considered, the time-specific effect becomes irrelevant.

Fortunately, panel data for most variables of interest is available. We intend to use the additional information contained in panel data to analyze regression equation (6).

III. PANEL DATA ESTIMATION

Let us rewrite equation (6) as follows:

$$z_{i,t} = \theta' x_{i,t} + (1+\gamma) z_{i,t-1} + \xi_t + \mu_i + e_{i,t} \tag{7}$$

where $z_{i,t} = \log(y_{i,t})$; $x_{i,t} = (\log(n_{i,t}+g+\delta)\ ,\ \log(s_{i,t}))'$; and $\theta = (\theta_n\ ,\ \theta_s)'$.

We assume that the independent regressors, x, are well measured in the data. However, we allow for the possibility of errors in variables regarding the dependent variable, z. Observed output may not correspond to the model's output variable for two reasons. First, output may be poorly measured. Second, and most importantly, observed output has a business cycle and a growth (or trend) component. Since our working model explains only the latter, there is a potential estimation bias. Errors in the dependent variable are a potential source of bias because lagged output is one of the regressors.

Let us consider the following estimation strategy. To account for the time effects we process the data by removing the time means from each variable. Then, we can ignore the ξ_t's and the regression can be fit without a constant (MaCurdy 1982).

Least-squares estimation ignoring the country-specific effects and the errors-in-variables problem produces biased estimators. In particular the estimate of $(1+\gamma)$ is biased in an unknown direction: the measurement error biases the estimate downwards, and the country-specific effect tends to bias it upwards.

Using the "within" estimator (or any other panel-data estimator based on time-differencing) to correct for the country-specific-effects bias is inappropriate. The specific-effects bias disappears, but the measurement-error downward bias tends to worsen; this is due to the reduction in "signal" variance brought about by time-differencing. Furthermore, given the presence of a lagged dependent variable, time-difference estimators by construction create an additional downward bias. Therefore, in general the "within" and other time-difference methods underestimate $(1+\gamma)$.

We will use the Π-matrix estimation procedure outlined in Chamberlain (1984). This procedure allows us to correct for both measurement-error and specific-effects biases. Chamberlain's Π-matrix estimation procedure consists of writing both the lag dependent variable and the country-specific effect in terms of the independent regressors, thus obtaining reduced-form regressions from which to obtain the coefficient estimates of interest. More specifically, the Π-matrix procedure consists of two steps: First, we estimate the parameters of the reduced-form regressions of the endogenous variable in each period in terms of the exogenous variables in all periods; thus, we estimate a multivariate regression system with as many regressions as periods for the endogenous variables are available. Since, we allow for group-wise heteroskedasticity and correlation between the errors of all regressions, we use the seemingly unrelated regression (SUR) estimator. As result of this first step, we obtain estimates of the parameters of the reduced-form regressions (these are the elements of the Π matrix) and the robust (White's heteroskedasticity-consistent) variance-covariance matrix of such parameters.

Our working model implies some restrictions on the elements of the Π matrix; or in other words, the parameters we are interested in are functions of the elements of the Π matrix. Then, in the second step of the procedure, we estimate the parameters of interest by means of a minimum distance estimator, using the estimated robust variance-covariance of the estimated Π as the weight matrix:

$$Min(Vec\Pi - f(\psi))' \ \Omega \ (Vec\Pi - f(\psi))$$

where ψ is the set of parameters of interest, and Ω is the robust estimated variance-covariance of the Π matrix. Chamberlain (1982) shows that this procedure obtains asymptotically efficient estimates.

In order to use this method, we need to make explicit the restrictions that our model imposes on the Π matrix. After removing the time means, our basic model in equation (6) can be written as

$$\begin{gathered} z_{i,t} = \theta' x_{i,t} + (1+\gamma) z_{i,t-1} + \mu_i + \epsilon_{i,t} \\ E[\epsilon_{i,t} | x_{i,1},...,x_{i,T} = 0] \quad for \quad t=1,...,T \end{gathered} \tag{8}$$

By recursive substitution of the z_{t-1} term in each regression equation, we have

$$z_{i,0} = z_{i,0}$$

$$z_{i,1} = \theta' x_{i,1} + (1+\gamma) z_{i,0} + \mu_i + \omega_{i,1}$$

$$z_{i,2} = (1+\gamma)\theta' x_{i,1} + \theta' x_{i,2} + (1+\gamma)^2 z_{i,0} + [1+(1+\gamma)]\mu_i + \omega_{i,2}$$

$$z_{i,3} = (1+\gamma)^2\theta' x_{i,1} + (1+\gamma)\theta' x_{i,2} + \theta' x_{i,3} + (1+\gamma)^3 z_{i,0} + [1+(1+\gamma)+(1+\gamma)^2]\mu_i + \omega_{i,3}$$

$$\vdots$$

$$z_{i,T} = (1+\gamma)^{T-1}\theta' x_{i,1} + \ldots + \theta' x_{i,T} + (1+\gamma)^T z_{i,0} + [1+(1+\gamma)+\ldots+(1+\gamma)^{T-1}]\mu_i + \omega_{i,T}$$

$$E^*(\omega_{i,t} \mid x_{i,1},\ldots,x_{i,T}) = 0 \qquad (t=1,\ldots,T \ \ and \ \ i=1,\ldots,N)$$

Chamberlain (1984) proposes to deal with the correlated country-specific effect (μ_i) and the initial condition ($z_{i,0}$) by replacing them by their respective linear predictors (given in terms of the exogenous variables) and error terms, which by construction are uncorrelated with the exogenous variables. The linear predictors are given by

$$E^*(z_{i,0} \mid x_{i,1}, x_{i,2}, \ldots x_{i,T}) = \lambda_1' x_{i,1} + \lambda_2' x_{i,2} + \ldots + \lambda_T' x_{i,T}$$

$$E^*(\mu_i \mid x_{i,1}, x_{i,2}, \ldots x_{i,T}) = \tau_1' x_{i,1} + \tau_2' x_{i,2} + \ldots + \tau_T' x_{i,T}$$

As Chamberlain points out, assuming that the variances are finite and that the distribution of ($x_{i,1}, \ldots, x_{i,T}, \mu_i$) does not depend on i, using the linear predictors does not impose any additional restrictions.

Now we are ready to write the Π matrix implied by our working model. As we will see in the next section, our panel data consists of 5 cross sections for the exogenous variables x and 6 cross sections for the variable z; the additional cross section for z is given by the initial condition z_0. Thus, the multivariate regression implied by our model is

$$\begin{bmatrix} z_{i,0} \\ z_{i,1} \\ z_{i,2} \\ z_{i,3} \\ z_{i,4} \\ z_{i,5} \end{bmatrix} = \Pi \cdot \begin{bmatrix} x_{i,1} \\ x_{i,2} \\ x_{i,3} \\ x_{i,4} \\ x_{i,5} \end{bmatrix} \tag{9}$$

$$\Pi = [B + \zeta \lambda' + \phi \tau']$$

where,

$$B = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ \theta' & 0 & 0 & 0 & 0 \\ (1+\gamma)\theta' & \theta' & 0 & 0 & 0 \\ (1+\gamma)^2\theta' & (i+\gamma)\theta' & \theta' & 0 & 0 \\ (1+\gamma)^3\theta' & (1+\gamma)^2\theta' & (1+\gamma)\theta' & \theta' & 0 \\ (1+\gamma)^4\theta' & (1+\gamma)^3\theta' & (1+\gamma)^2\theta' & (1+\gamma)\theta' & \theta' \end{bmatrix}$$

$$\zeta\lambda' = \begin{bmatrix} 1 \\ (1+\gamma) \\ (1+\gamma)^2 \\ (1+\gamma)^3 \\ (1+\gamma)^4 \\ (1+\gamma)^5 \end{bmatrix} \cdot \begin{bmatrix} \lambda_1' & \lambda_2' & \lambda_3' & \lambda_4' & \lambda_5' \end{bmatrix}$$

$$\phi\tau' = \begin{bmatrix} 0 \\ 1 \\ 1+(1+\gamma) \\ 1+(1+\gamma)+(1+\gamma)^2 \\ 1+(1+\gamma)+(1+\gamma)^2+(1+\gamma)^3 \\ 1+(1+\gamma)+(1+\gamma)^2+(1+\gamma)^3+(1+\gamma)^4 \end{bmatrix} \cdot \begin{bmatrix} \tau_1' & \tau_2' & \tau_3' & \tau_4' & \tau_5' \end{bmatrix}$$

As we said in the introduction, we would also like to consider the case in which we have some information as to one of the elements of the country-specific factors, namely, the country's level of education. In this case, we rewrite equation (8) as follows,

$$\begin{aligned} z_{i,t} &= \theta' x_{i,t} + (1+\gamma) z_{i,t-1} + \theta_e e_i + \nu_i + \epsilon_{i,t} \\ E\left[\epsilon_{i,t} \mid x_{i,1},\ldots,x_{i,T}, e_i\right] &= 0 \qquad \textit{for} \quad t = 1,\ldots,T \end{aligned} \tag{10}$$

where, e_i is a proxy for the country's level of education (which is assumed to be constant through time), θ_e is a constant coefficient, and ν_i is the new country-specific factor. By definition $\mu_i = \theta_e e_i + \nu_i$.

In this case, the associated multivariate regression is very similar to the one where no information as to the country-specific effects is available. Working with recursive substitution and the appropriate linear predictors, as we did in the previous case, the multivariate regression associated with regression equation (10) is the following,

$$\begin{bmatrix} z_{i,0} \\ z_{i,1} \\ z_{i,2} \\ z_{i,3} \\ z_{i,4} \\ z_{i,5} \end{bmatrix} = \Pi \cdot \begin{bmatrix} x_{i,1} \\ x_{i,2} \\ x_{i,3} \\ x_{i,4} \\ x_{i,5} \\ e_i \end{bmatrix} \tag{11}$$

$$\Pi = [B + \zeta\lambda' + \phi\tau']$$

where,

$$B = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ \theta' & 0 & 0 & 0 & 0 & 0 \\ (1+\gamma)\theta' & \theta' & 0 & 0 & 0 & 0 \\ (1+\gamma)^2\theta' & (1+\gamma)\theta' & \theta' & 0 & 0 & 0 \\ (1+\gamma)^3\theta' & (1+\gamma)^2\theta' & (1+\gamma)\theta' & \theta' & 0 & 0 \\ (1+\gamma)^4\theta' & (1+\gamma)^3\theta' & (1+\gamma)^2\theta' & (1+\gamma)\theta' & \theta' & 0 \end{bmatrix}.$$

$$\zeta\lambda' = \begin{bmatrix} 1 \\ (1+\gamma) \\ (1+\gamma)^2 \\ (1+\gamma)^3 \\ (1+\gamma)^4 \\ (1+\gamma)^5 \end{bmatrix} \cdot \begin{bmatrix} \lambda_1' & \lambda_2' & \lambda_3' & \lambda_4' & \lambda_5' & \lambda_e \end{bmatrix}$$

$$\phi\tau' = \begin{bmatrix} 0 \\ 1 \\ 1+(1+\gamma) \\ 1+(1+\gamma)+(1+\gamma)^2 \\ 1+(1+\gamma)+(1+\gamma)^2+(1+\gamma)^3 \\ 1+(1+\gamma)+(1+\gamma)^2+(1+\gamma)^3+(1+\gamma)^4 \end{bmatrix} \cdot \begin{bmatrix} \tau_1' & \tau_2' & \tau_3' & \tau_4' & \tau_5' & (\tau_e+\theta_e) \end{bmatrix}$$

From the implied restrictions on the Π-matrix (in particular those related to the coefficients on e_i), note that we cannot separate τ_e from θ_e: only $(\tau_e + \theta_e)$ is identified. Therefore, even though the level of education help condition for the country-specific factor, its precise effect on growth is not identified without further restrictions.

IV. DATA AND RESULTS

The data source for all our variables, but the proxy for the level of education, is The Penn World Table (Mark 5), constructed by R. Summers and A. Heston (1991). This table provides annual information for a number of national accounts variables from around 1950 to 1988. However, data for most countries is available only for a shorter period of time, namely, 1960 to 1985. We work with regular non-overlapping intervals of five years each. Thus, our five cross sections correspond to the years 1965, 1970, 1975, 1980, and 1985. Let us explain each of the variables of the model in turn. The dependent variable is the natural logarithm of real GDP per worker, that is, $\log(y_{i,65})$, ..., $\log(y_{i,85})$.

When no information as to the country-specific factors is available, the regression equation has three explanatory variables (equation (8)). The first one is the natural logarithm of the working-age population average growth rate plus $(g+\delta)$; we follow Mankiw, et. al. (1992) in assuming that $(g+\delta)=0.05$. The average of the working-age population growth rate is taken over the previous five-year interval; then we also have five observations of this variable for each country, that is, $\log(n_{i,65}+0.05)$, ..., $\log(n_{i,85}+0.05)$.

The second explanatory variable is the natural logarithm of the average ratio of real investment (including government investment) to real GDP. These averages are also taken over the previous five-year interval, so that we have five observations for each country, that is, $\log(s_{i,65})$, ..., $\log(s_{i,85})$.

The last explanatory variable is the natural logarithm of real GDP per worker lagged one period, that is, five years back; therefore, the observations for each country are,

$\log(y_{i,60})$, ..., $\log(_{i,80})$.

We would also like to consider the case in which we have some information as to one of the elements of the country-specific effects, in particular, the country's level of education (equation (10)). The proxy we use for the level of education is taken from Mankiw, Romer, and Weil (1992). This is the percentage of the working-age population that is enrolled in secondary school, a measure that is approximated by the product of the gross secondary enrollment ratio times the fraction of the working age population that is of secondary school age (i.e., aged 15 to 19).

Our sample consists of 98 countries (see Appendix B for a list of countries considered). These are the countries for which data are available and for which oil production is not the primary economic activity. It is well known that standard growth models do not account for economies based on the extraction of natural resources and not on value-added activities. Excluding the countries for which data are not available may create sample selectivity problems given that these countries are frequently the poorest ones. Therefore, we will not presume that the results obtained here can be applied to those very poor economies.

Equations (8) and (10) represent the cases we wish to study. Writing those two equations more explicitly, we have

$$\log y_{i,t} = \theta_n \log(n_{i,t}+0.05) + \theta_s \log s_{i,t} + (1+\gamma)\log y_{i,t-5} + \mu_i + \varepsilon_{i,t} \qquad (8')$$

$$\log y_{i,t} = \theta_n \log(n_{i,t}+0.05) + \theta_s \log s_{i,t} + (1+\gamma)\log y_{i,t-5} + \theta_e e_i + \nu_i + \epsilon_{i,t} \quad (10')$$

Under the Solow growth model with a Cobb-Douglas aggregate production function (see equation (4)), we should expect the estimated values of γ to be negative, θ_n, negative, and θ_s, positive; furthermore, we expect θ_n and θ_s to be approximately the same in absolute value. In tables 1-3, we provide test statistics for such hypotheses.

Table 1 shows the estimated parameters of the simple Solow model in equation (8') using conventional procedures. The OLS and 1st-differences estimators refer to least squares estimation in levels and 1st-differences, respectively. In order to use the information from the 5 available cross-sections, we employ a system-regression procedure, considering parameter and covariance restrictions across the regressions of the system.[1] As is well known, the Within estimator falls under the category of difference estimators.

As explained in section III, the OLS estimator ignores both errors-in-variables and country-specific effects, thus producing estimates for γ that are biased in an *a priori* unknown direction. The difference estimators control for country-specific effects but ignore the errors-in-variables problem and, by construction, create a correlation between the new error term and the differenced lagged dependent variable. Therefore, difference estimators produce downward-biased estimates for γ. Such downward bias is worse in the case of the 1st-differences estimator than in the case of the Within estimator.

Table 2 shows the estimated parameters of the simple Solow model in both equations

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[1]Clearly, each regression in the system corresponds to one cross-section.

(10') and (8') (that is, with and without education as a regressor) using Chamberlain's Π-matrix procedure. In each case we estimate both ignoring and accounting for country-specific effects. Given that through the Π-matrix procedure the endogenous variable, output, is not used as a regressor, its related errors-in-variables no longer produces estimation bias. Therefore, Π-matrix estimation assuming no country specific effects has no errors-in-variables bias but presents country-specific effects bias, which, as explained in section III, is an upward bias. Clearly, this bias is worse when the proxy for education, as an element of the country-specific effects, is not used as a regressor than when it is.

Π-matrix estimation accounting for country-specific effects produces unbiased estimates; when, additionally, the proxy for education is used as a regressor, the parameter estimates gain efficiency.

In the context of the Π-matrix method, it is possible to test whether country-specific effects are important, in the sense that they are correlated to the independent regressors. Note that the absence of country-specific effects implies that the coefficients in the linear predictor of μ_i are all equal to zero, that is, H_0: $\tau'_1 = \ldots = \tau'_5 = 0$. As we can see in Table 2, the appropriate Wald test for this hypothesis strongly rejects it. Controlling for country-specific effects is in fact quite important.

From Tables 1 and 2, we learn that the estimates for γ obtained using various procedures agree with our predictions, in terms of how such estimates are related to consistent estimates. The 1st-differences estimate for γ (-0.9786) is the most negative, followed by the Within estimate (-0.3457). Then we have the estimates using the Π-matrix accounting for country-specific effects (-0.2187 and -0.2686, with and without using the education proxy, respectively). The OLS estimate (-0.0301) is next, showing that in this case the country-specific bias is stronger than the errors-in-variables bias. The highest (and only positive) estimate for γ is obtained using the Π-matrix procedure assuming no country-specific effects (0.0078), estimator which isolates the upward bias due to country-specific factors.

Our consistent estimates for γ imply the following values for β, the speed of convergence: .0626 (not using the education variable) and .0494 (using it). These values are about two and a half and three times as high as those obtained in previous empirical papers (see in particular Barro and Sala-i-Martin (1992), and Mankiw, Romer, and Weil (1992)). A figure commonly provided in studies of convergence is the "half life," which is the time it takes for an economy to move halfway to its own steady state. From equation (1), we find that the half life, T, can be calculated from an estimate of β as follows

$$T = \frac{\log 2}{\beta}$$

Therefore, the Π-matrix method controlling for country-specific effects and using the education proxy as a regressor predicts a half life of about 14 years, while previous studies, suffering from errors-in-variables and specific effects biases, predict one of about 34.7 years. This could be interpreted as "good news" for poor countries. However, such interpretation would be inappropriate since the convergence occurs with respect to the country's own steady state level. As we will say later on, a higher rate of convergence is related to a low share of physical capital in the production function, which implies that decreasing returns set in more quickly.

Comparing the Π-matrix consistent estimates for the coefficients on labor force growth and investment ratio (θ_n and θ_s, respectively) with their OLS counterparts, we see that the consistent estimates are stronger (i.e., higher in absolute value) and more efficient (i.e., with a lower standard error). Comparing the two consistent estimators, we see that when the education proxy is used as a regressor, the effect of labor force growth and investment on output growth is somehow weaker.

In Tables 1 and 2 we report a Wald test for the hypothesis that θ_n and θ_s have the same absolute value and opposite signs. From equation (4), we realize that if the restriction that $\theta_s = -\theta_n$ is imposed in the model, it is possible to retrieve an implied estimate for α, the capital share in the Cobb-Douglas production function. We impose such restriction and report the constrained estimation results in Table 3. Not surprisingly our OLS estimates for β and α are very close to those obtained by Mankiw, et. al. (their estimates are $\beta = 0.00606$ and $\alpha = 0.7$ to 0.8) when they use the simple Solow model. The Π-matrix estimates ignoring country-specific effects but controlling for education are similar to those obtained by Mankiw, et. al. when they use their "human-capital augmented" Solow model (their estimates are $\beta = 0.0137$ and $\alpha = 0.48$). Properly accounting for country-specific effects, we obtain estimates for α that are much closer to the accepted benchmark value[2]: 0.335 (not using the education proxy) and 0.347 (using it). Interestingly, Mankiw, et. al. argue that the simple Solow model performs well in their cross-sectional study except for the fact that their estimated α is much bigger than the accepted benchmark value.

[2]Maddison (1987) estimates the share of non-human capital in production to be about 0.35.

V. CONCLUSION

This study estimates the rate of convergence of an economy to its own steady state. Using panel data for a sample of 98 countries, we use Chamberlain's (1984) estimation procedure is applied to account for the presence of country-specific effects, which result from idiosyncratic unobservable factors. Furthermore, this procedure avoids the estimation bias due to measurement error in GDP. Controlling, additionally, for the country's level of education, we estimate the rate of convergence, β, to be 0.0494; which implies a half life of about 14 years. Also, we estimate the capital shaie in production, α, to be 0.347. We believe that our estimated rate of convergence (which is higher than in other studies) provides evidence in favor of the neoclassical Solow model, in which only physical capital can be accumulated. The Solow model predicts a rapid rate of convergence because it considers a production function with strong decreasing returns to capital, the factor that can be accumulated. In the simple Cobb-Douglas specification, such strong decreasing returns are produced by a low capital share (α, in our case). In fact, the Solow model with a Cobb-Douglas production function gives a closed-form solution for the rate of convergence,

$$\beta = (n+g+\delta)(1-\alpha)$$

Assuming that $g+\delta = 0.05$, and using the average working-population growth rate for our sample, $n = 0.022$, we find that a value of 0.347 for α implies a rate of convergence β of 0.047, which is very similar to our econometrically estimated rate of convergence.

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Table 1: Estimation of the Simple Solow Model Using Conventional Procedures			
Parameters	OLS	1st-Differences	Within
γ	-.0301 (.0109)	-.9786 (.0741)	-.3457 (.0378)
θ_n	-.0756 (.0513)	-.0600 (.0364)	-.1140 (.0542)
θ_s	.1055 (.0179)	.2184 (.0363)	.1745 (.0241)
Implied β	.0061 (.0022)	.7689 (.6925)	.0848 (.0116)
Wald Test for $\theta_n = -\theta_s$	.2822	8.1713	2.1216
p-value	.5953	.0043	.0488

Table 2: Estimation of the Simple Solow Model Using Chamberlain's Π-Matrix Procedure				
Parameters	No Specific Effects	Specific Effects	No Specific Effects, Controlling for Education	Specific Effects, Controlling for Education
γ	.0078 (.0051)	-.2686 (.0456)	-.0670 (.0077)	-.2187 (.0474)
θ_n	-.0195 (.0192)	-.1220 (.0250)	-.0892 (.0224)	-.0948 (.0244)
θ_s	.0585 (.0091)	.1489 (.0178)	.0878 (.0077)	.1305 (.0154)
Implied β	-.0016 (.0010)	.0626 (.0125)	.0139 (.0016)	.0494 (.0121)
Wald Test for $\theta_n = -\theta_s$	2.4784	.7975	.0028	1.2980
p-value	.1154	.3718	.9579	.2546
Wald Test for No Specific Effects	-	164.5277	-	134.1383
p-value		.0000		.0000

Table 3: Estimation of the Simple Solow Model Imposing the Cobb-Douglas Restriction: $\theta = -\theta_n = \theta_s$

Parameters	OLS	Π-Matrix No Specific Effects, Controlling for education	Π-Matrix Specific Effects	Π-Matrix Specific Effects, Controlling for Education
γ	-.0311	-.0669	-.2782	-.2262
	(.0113)	(.0075)	(.0437)	(.0458)
θ	.1028	.0881	.1401	.1202
	(.0165)	(.0064)	(.0147)	(.0119)
Implied β	.0063	.0138	.0652	.0513
	(.0023)	(.0016)	(.0121)	(.0118)
Implied α	.7679	.5684	.3350	.3470
	(.0472)	(.0236)	(.0418)	(.0572)
Wald Test for No Specific Effects	-	-	170.5039	129.3814
p-value			.0000	.0000

APPENDIX. List of Countries in the Sample.

Algeria
Angola
Benin
Bostwana
Burkina Faso
Burundi
Cameroon
Central Afr. Rep.
Chad
Congo
Egypt
Ethiopia
Ghana
Ivory Coast
Kenya
Liberia
Madagascar
Malawi
Mali
Mauritania
Mauritius
Morocco
Mozambique
Niger
Nigeria
Rwanda
Senegal
Sierra Leone
Somalia
South Africa
Sudan
Tanzania
Togo
Tunisia
Uganda
Zaire
Zambia
Zimbabwe
Bangladesh
Burma
Hong Kong
India
Israel
Japan
Jordan
Korea, Rep. of
Malaysia
Nepal
Pakistan
Philippines
Singapore
Sri Lanka
Syrian Arab Rep.
Thailand
Austria
Belgium
Denmark
Finland
France
Germany, Fed. Rep.
Greece
Ireland
Italy
Netherlands
Norway
Portugal
Spain
Sweden
Switzerland
Turkey
United Kingdom
Canada
Costa Rica
Dominican Rep.
El Salvador
Guatemala
Haiti
Honduras
Jamaica
Mexico
Nicaragua
Panama
Trinidad and Tobago
United States
Argentina
Bolivia
Brazil
Chile
Colombia
Ecuador
Paraguay
Peru
Uruguay
Venezuela
Australia
Indonesia
New Zealand
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